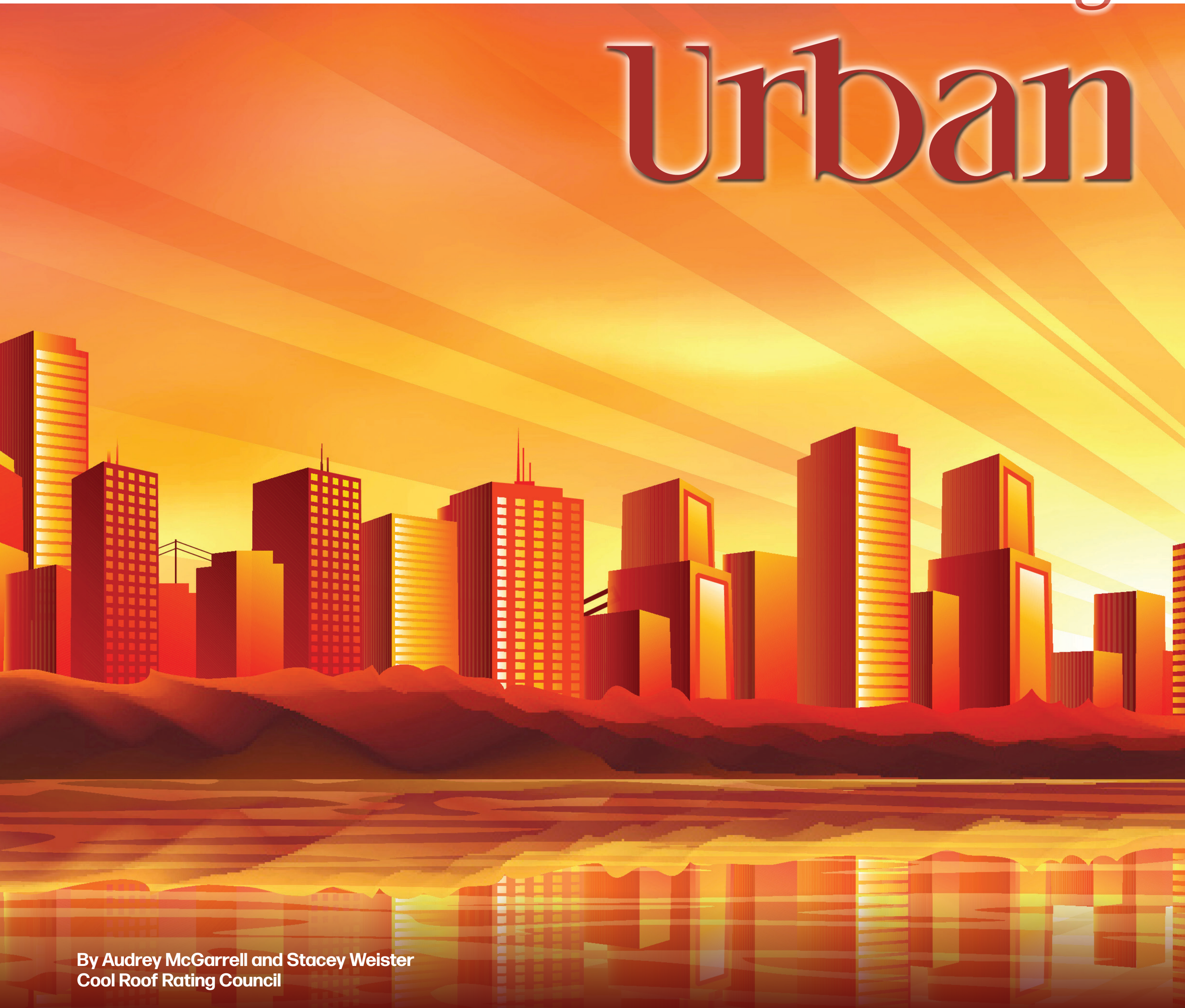
Urban



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Heat is the leading weather-related cause of human mortality, surpassing hurricanes, tornadoes, lightning, and blizzards. The impacts of heat are intensified by the urban heat island (UHI) effect, which occurs when cities are hotter than surrounding rural and suburban areas. Architectural coatings can play an important role in UHI mitigation by reflecting solar radiation rather than absorbing it. By efficiently reflecting sunlight and emitting absorbed heat, cool exterior walls maintain a lower surface temperature, improve occupant comfort and safety, and reduce the demand for air conditioning, which decreases the building's contribution to peak demand, greenhouse gas emissions, and the UHI effect. This article describes methods for evaluating the "coolness" of architectural coatings, including laboratory testing and natural weathering to determine the durability of the radiative properties. It also summarizes current technologies for increasing coating solar reflectance; discusses the latest research on the impacts of cool exterior walls; describes U.S. building codes, standards, and voluntary programs that require or promote their use; and explores strategies for discussing cool coatings with customers.

Introduction

The urban heat island (UHI) effect is a growing concern among communities in the United States and across the

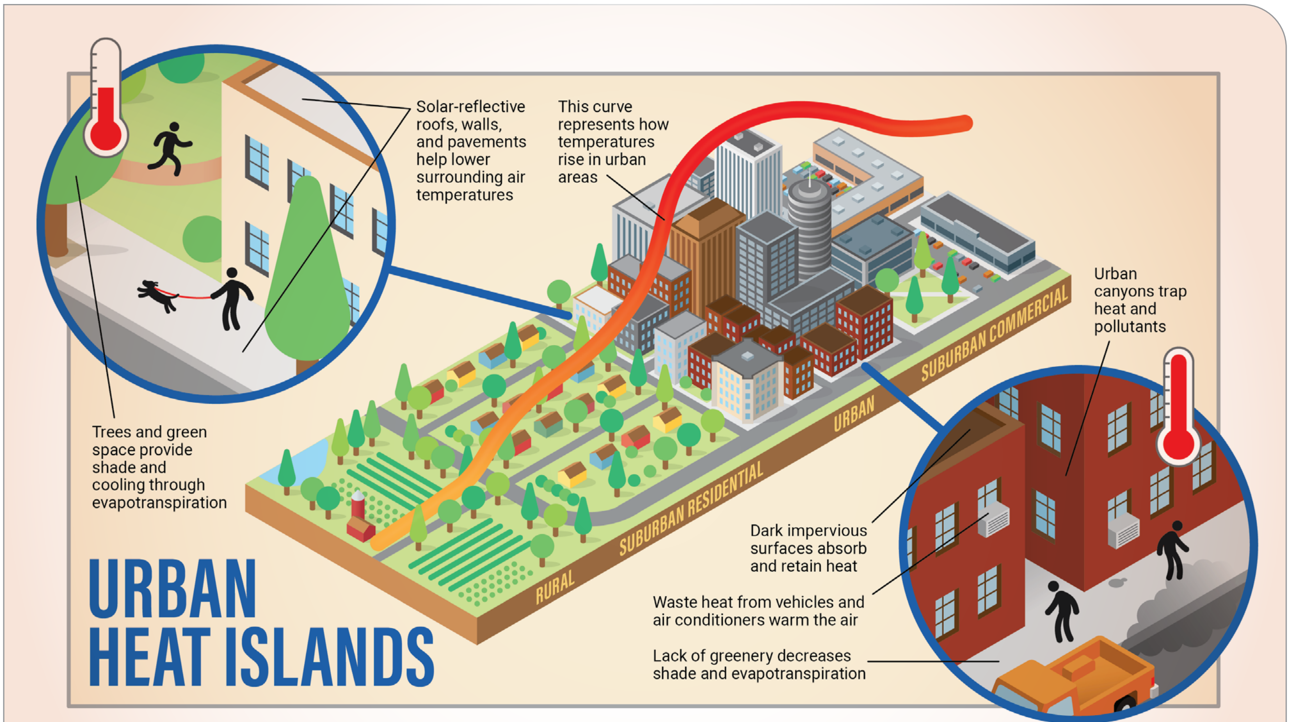
as a Tool for Combating Heat Islands

globe. Architectural coatings that highly reflect solar radiation and emit absorbed heat are an effective tool to combat urban heat and make communities safer and more comfortable. This article outlines the issue of urban heat and offers "cool" coatings as one solution that is gaining traction. We explore how cool exterior walls work; how the cooling properties of products are evaluated; examples of current technologies; adoption in codes, standards, and programs; and how they fit into sustainability efforts and marketing in the architectural coatings industry.

The Urban Heat Island Effect

Heat is the greatest weather-related cause of human mortality—surpassing hurricanes, tornadoes, lightning, and blizzards.[1] Extreme heat can also cause heat illness and increased respiratory and cardiovascular problems, which can strain health services, as well as create disruptions to key infrastructure such as power grids and water supplies.[2] The negative impacts of extreme heat are intensified by the urban heat island (UHI) effect, a phenomenon in which cities are hotter than surrounding rural and suburban areas. According to the U.S. Environmental Protection Agency (EPA), daytime temperatures in urban areas are about 0.6 °C to 3.9 °C (1 °F to 7 °F) higher than temperatures in outlying areas, with nighttime temperatures about 1.1 °C to 2.8 °C (2 °F to 5 °F) higher.[3] This

FIGURE 1
Explanation of the urban heat island effect.



This illustration describes the factors that contribute to urban heat islands (UHI), as well as factors that help mitigate UHI. Urban heat islands occur when the temperature in urban environments is higher than surrounding areas. High surface temperatures lead to elevated air temperatures, especially at night. Heat islands increase heat-related discomfort, illness, and death. They also cause greater air conditioner use, which increases energy costs and air pollution. Urban heat has a disproportionate impact on disadvantaged communities (Hsu et al., 2021; Hoffman et al., 2020; and Wilson, 2020).

Image Credit: Cool Roof Rating Council

temperature difference occurs because heat from the sun is retained in areas with a high concentration of buildings, parking lots and roads, and a lack of trees and green space (see **Figure 1**). Tall buildings that block or slow air movement, along with waste heat released by vehicles and air-conditioning units, contribute to the formation of UHIs. Smaller, more intense heat islands also exist within cities, and they can disproportionately affect low-income neighborhoods and communities of color.[4,5,6]

Although air-conditioning can help keep buildings safe and comfortable, increased air-conditioning use also releases waste heat into the environment, exacerbating already hot temperatures. Furthermore, not all homes and businesses are equipped with air conditioning. For example, the *New York Times* reported that, in the heat waves that occurred in Oregon and Washington state in June 2021, an estimated 600 more people died than would normally be expected during that time period.[7] Fewer than two-thirds of homes in Oregon have air conditioning, and only 44% of households in the Seattle metropolitan area have it.[8] In Multnomah County, OR, where Portland is located, none of the people who passed away during the 2021 heat waves had central air-conditioning.[7]

In addition to the immediate threats of extreme heat, hot temperatures also have indirect consequences, such as increased formation of ground-level ozone, a key ingredient in smog and a dangerous pollutant, especially for individuals with existing respiratory conditions.[9] The increased energy used to power air conditioners during hot times can also lead to greater use of as-needed power plants, commonly known as "peaker" plants, which are large emitters of air pollution and contribute to blackouts and brownouts due to electrical grid strain.

Heat waves across the United States continue to be more frequent, longer, and more intense,[10] and scientists predict that cities across the globe will be approximately 4 °C (7.2 °F) hotter by 2100 due to climate change.[11] As such, solutions to keep buildings and communities cooler are increasingly important.

Cool Coatings as a Tool to Mitigate UHI

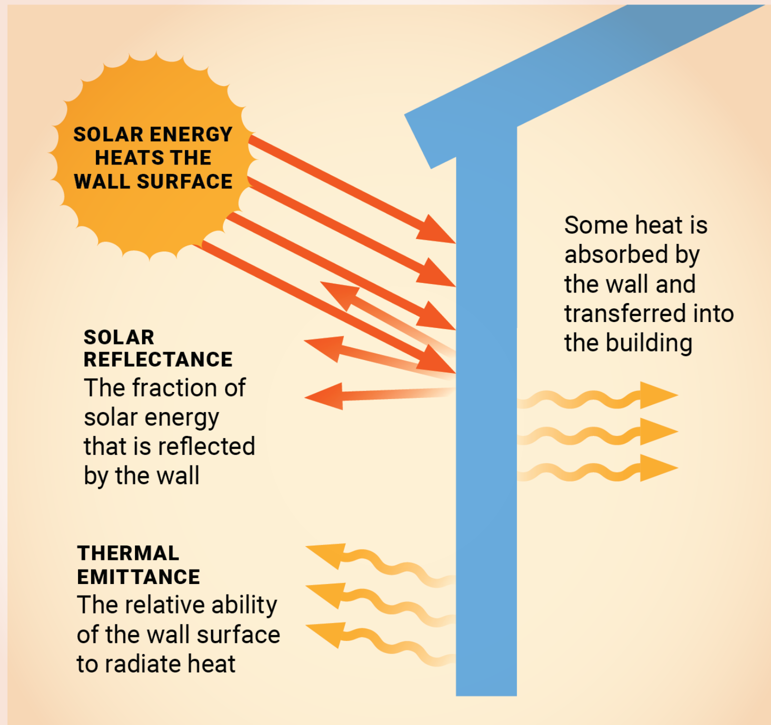
The building envelope can play an important part in mitigating the UHI effect through the use of "cool" surface materials, such as roofs, exterior walls, and pavements. Cool surfaces are exterior surfaces that are made from materials that efficiently reflect sunlight and emit absorbed heat. This article addresses cool exterior walls, a concept that is relatively new compared to cool roofs, which are gaining popularity as a tool to combat urban heat and save energy.

Cool exterior walls are typically light in color or contain additives or special pigments that efficiently reflect infrared radiation and re-radiate absorbed heat. This keeps the surface temperature of the wall cooler and reduces the building's solar heat gain (the amount of heat from the sun that enters the building), thus maintaining cooler indoor temperatures than would occur if less-reflective exterior wall materials were used. **Figure 2** is a simple illustration of how cool exterior walls work. The two basic characteristics that determine the "coolness" of the wall surface are solar reflectance (SR) and thermal emittance (TE). Both properties are measured on a scale from 0 to 1, where 1 is 100% reflective or emissive. The same properties are used to evaluate the radiative performance of roofing materials. A detailed discussion of how these properties are measured is included in the following section.

In 2019, the California Energy Commission published a study led by Lawrence Berkeley National Laboratory, the University of Southern California, and the University of California at San Diego that demonstrated that cool exterior walls are a viable mechanism for UHI mitigation on par with cool roofs, yielding about 85% of the daily average air cooling achieved with cool roofs in July in Los Angeles, CA.[12] Although exterior walls receive less daily solar irradiance than roofs, they also generally have less insulation than roofs, with about half the amount of resistance to heat flow achieved by a roof. The combination of these two factors results in cool exterior walls and cool roofs having similar impacts.[12] The researchers also found that cool exterior walls produce annual HVAC energy savings in U.S. Climate Zones 1 through 4 (southern half of the United States) and across all 16 of California's climate zones for both residential and nonresidential buildings.[13]

When an exterior wall surface highly reflects solar radiation, it lowers the surface temperature of the wall material (**Figure 3**)

FIGURE 2
Cool exterior wall diagram.



This illustration describes the flow of radiant energy as heat between the sun, wall surface, building interior, and surroundings. The higher the solar reflectance, the more solar energy is reflected away from the wall surface. Some of the solar energy is absorbed by the wall as heat. The higher the thermal emittance, the more absorbed heat is radiated away from the wall surface.

Image Credit: Cool Roof Rating Council

FIGURE 3
Difference between the surface temperature of a dark exterior wall (160.7 °F) and a light exterior wall (114.4 °F) on July 19, 2022, at 7 p.m. in Portland, OR.

Image Credit: Audrey McGarrell

and reduces the building's solar heat gain. This causes a chain reaction of effects on individual building, community, and global scales.

Reduced heat gain lowers the building's indoor temperature. For non-air-conditioned buildings, this improves occupant comfort and safety, especially during heat waves.[14] For air-conditioned buildings, reduced heat gain helps lower the building's cooling demand[13] and, by extension, reduces the amount of waste heat released by air-conditioning units. Less waste heat leads to lower outdoor temperatures, which improves air quality by slowing the formation of ground-level ozone that can trigger severe health problems and contribute to smog formation.[9]

Reduced cooling demand also helps decrease peak power demand,[13] which can alleviate strain on the electrical grid, lowering the risk of blackouts and brownouts, and lessen the use of peaker plants. Reductions in peak and conventional power generation decrease the emission of greenhouse gasses, which helps address the greenhouse effect and the impacts of climate change.[13]

The outcomes associated with cool exterior walls for an individual structure can depend on a variety of factors, including, but not limited to, wall SR, wall insulation and construction, climate zone, building orientation, and building occupant use. Though cool exterior walls have been shown to reduce a building's cooling demand in U.S. Climate Zones 1 through 4 and across California, they can also cause heating bills to increase during the winter because they do not absorb as much sunlight as darker or less solar-reflective exterior walls. The magnitudes of energy savings and penalties from cool exterior walls depend on several key factors, including climate, wall construction, wall orientation, building orientation, and HVAC efficiency. Rosado and Levinson[13] found that installing cool exterior wall technology on the south-facing wall of a building in California led to the largest penalties in terms of heating costs. However, the same arrangement led to large savings during the cooling season. Across California and the southern half of the United States, the study also found that all buildings of any vintage would benefit from cool exterior walls, especially on the east, south, and west faces.

Evaluating the Coolness of Architectural Coatings

In order for end users to evaluate the potential cooling benefits of product options, it is important for credible test data to be available. Several ASTM International standards and other industry-vetted test methods can be used to determine the SR of a coating, but the most common method is ASTM C1549.[15] This test method uses a portable reflectometer, such as the Devices and Services Solar Spectrum Reflectometer (SSR). To account for how the wall surface interacts with solar radiation, the SR of architectural coatings is measured using an irradiance model specific to a sun-facing 90° (vertical) tilted surface.

The TE of architectural coatings is measured using a portable emissometer, such as the Devices and Services AE1 Portable Emissometer, in accordance with a variant of ASTM C1371[16] known as the Slide Method, which is published in the Devices and Services Company's Technical Note 11-2.[17] The Slide Method is a testing technique in which the emissometer head is moved across the surface without creating a gap between the surface and the emissometer head every 15 seconds. Using the Slide Method on products with high thermal resistance prevents excess heat gain in test specimens that are poor conductors. The non-modified ASTM C1371 test method is only appropriate for products with a thermal conductance greater than 1100 W/m2·K, such as factory-coated metal or uninsulated bare metal.[16]

The Solar Reflectance Index (SRI), calculated in accordance with ASTM E1980, is a common metric used for comparing the overall ability of a roof material to stay cool, but it is not applicable to exterior wall materials because the formula to calculate the SRI does not account for vertical surfaces.[18] Future research could lead to the development of an SRI calculation suitable for exterior wall products, but at this time, it is not an appropriate metric.

Natural weathering and aged testing are important steps in evaluating a coating's radiative performance over time. Following the measurement of new products, specimens are exposed to natural weathering for three years by accredited test farms in three different locations (Arizona, Ohio, and Florida), which represent different climate zones (hot/dry, cold/temperate, and hot/humid) in the United States to assess the long-term performance. Specimens are exposed to natural weathering in accordance with ASTM G7 at 90° South in an offset rack that horizontally staggers specimens to minimize cross-contamination. Researchers at Lawrence Berkeley National Laboratory found that three years is an appropriate timeframe to indicate how exterior wall products will perform over time, with the studied specimens displaying minimal SR loss over three years, and even less change on average between the second and third years of exposure.[19]

While not all products will experience significant variation in SR when exposed to the elements, natural weathering exposure is critical to help users understand a product's radiative performance over time. Build-up of dirt and dust, high temperatures, precipitation, and ultraviolet (UV) radiation can all contribute to changes in radiative performance.

In the roofing industry, ASTM D7897 provides a standard laboratory soiling and weathering procedure that replicates the effects of three years of natural exposure, including soiling and weathering, on the solar reflectance and thermal emittance of roofing products.[20] The radiative properties of each specimen are measured before and after laboratory soiling and laboratory weathering to provide temporary, simulated aged values that can be used for compliance with building energy codes until natural weathering is completed. A laboratory aging procedure does not currently exist for exterior wall coatings. This is an area for potential future study.

Due to the complexity of testing the initial and aged radiative properties of paints and coatings, independent, third-party product ratings provide assurance that the radiative property data are credible and accurate, having been obtained using consensus standards and industry-vetted test methods, and are validated using quality assurance mechanisms. Third-party ratings inform consumers about the material's ability to reduce solar heat gain. The rating is based on data from an accredited independent testing laboratory that is verified and published by a third-party entity. A third party can be a government agency, a nonprofit organization, or a business that is not involved in the manufacturing or distribution of exterior wall products. Third-party product ratings are widely used by government agencies and energy

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utilities in the development, compliance, and enforcement of policies and programs that require or promote the use of specific building materials.

The Cool Roof Rating Council (CRRC) maintains a publicly available database of exterior wall products with radiative property ratings.[21] The database is a free online resource designed to help end users, such as architects, specifiers, and designers; facility managers; and home and building owners search for and identify products that can be used to comply with codes, standards, and green building certification programs as well as company or individual sustainability goals. Products are searchable by keyword, product type, manufacturer, brand or model, color, product market, and SR and TE values. Published ratings are obtained in accordance with the CRRC Wall Rating Program requirements,[22] which were developed with input from a wide array of stakeholders and subject matter experts.

Current Technologies

Using white or light-colored paint is one of the simplest ways to achieve cooling benefits. Lighter pigments inherently reflect more solar energy than darker colors, so bright white, off-white, and pastel colors can all have cooling benefits. For example, a standard dark- to medium-colored paint might reflect 25% of sunlight, whereas a typical off-white or dull-white paint might reflect 60%. A clean wall painted bright white could reflect more than 80% of sunlight.

Aside from light colors, pigments that reflect near-infrared (n-IR) wavelengths can be used to increase the solar reflectance of a coating. The coated metal industry has been using such pigments, which are referred to as infrared-reflecting (IR) pigments, for years to produce visually darker colors that have a higher SR than they would if conventional pigments were used (**Figure 4**). While all components of a coating have some bearing on its overall solar reflectance, pigments have the most impact on the n-IR reflectance.[23] There are three types of IR pigment technologies, and the most common are inorganic infrared-reflecting black pigments. These pigments are Complex Inorganic Color Pigments (CICP) that are chemically formulated to reflect n-IR waves and provide stable color.[24]

Organic infrared-transmitting black pigments are a less common infrared-reflecting technology. These pigments create dark colors that are visually opaque but transmit n-IR waves. When applied over a highly infrared-reflective substrate, these pigments provide dark colors with high solar reflectance. Because these pigments are organic, they are less durable for building applications.[24] Lastly, if color is not a factor, infrared-optimized titanium dioxide pigments are also available that achieve an even higher solar reflectance than standard titanium dioxide, which is already highly reflective, especially when applied to a dark surface.[24]

Specially formulated architectural coatings on the market today use various proprietary technologies to achieve high solar reflectance, such as infrared-reflective technology similar to what is used in military applications to reduce the heat signature of vehicles; coatings that form a reflective membrane once applied; and coatings that combine a highly reflective formulation with photocatalytic technology to create a self-cleaning effect.[25,26,27]

Recent academic research has also explored the development and impacts of more specialized technologies, such as bilayer coatings, retro-reflective coatings,

FIGURE 4
Solar reflectance values of conventional and infrared reflective (spectrally selective) pigments.

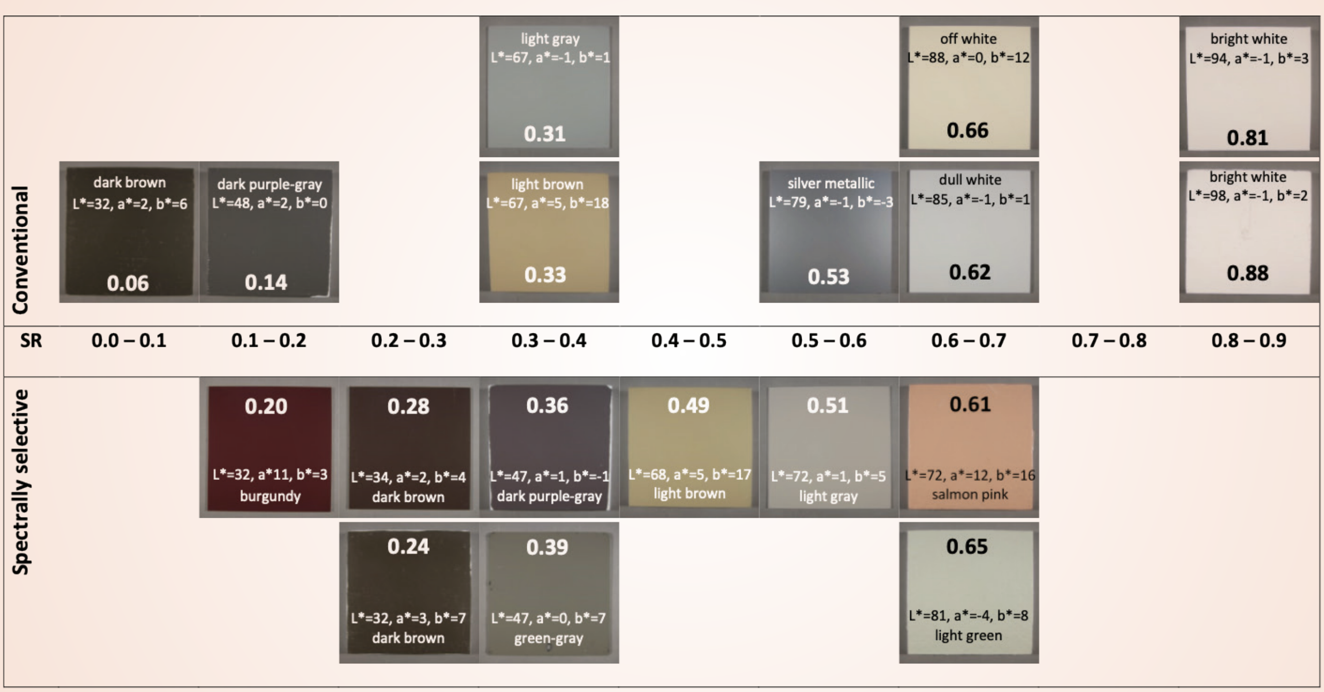

Image Credit: Heat Island Group, Lawrence Berkeley National Laboratory, Berkeley, CA. Used with permission.

SRI is a calculated metric that is only applicable to roofs; however, it is also included in some code provisions for exterior walls. To address this issue, several codes have been revised to include SR and TE instead of SRI.

and "super white" paints. A 2020 article published in *Science Advances* explores a bilayer coating that incorporates a top layer that selectively absorbs visible light to achieve a particular color over a base layer that highly backscatters sunlight that passes through the first layer. This results in a surface that is comparable in color to conventional paints, but remains much cooler in the sun.[28]

Retro-reflective coatings are ones that reflect solar radiation in the same direction that it is received. A 2022 study published in the journal *Energy and Buildings* found that retro-reflective coatings can significantly cool outdoor air temperatures and prevent neighboring buildings from absorbing reflected radiation in high-density urban environments. The coating used in this experiment was a prism retro-reflector, which returns sunlight at its original angle of incidence using prisms that refract the solar rays.[29]

Researchers have also recently explored the concept of developing "super white" paints formulated with ultraviolet-reflective pigments and other additives. Such coatings have the potential to reach sub-ambient temperatures, meaning the surface is cooler than the surrounding outdoor air. This technology has important limitations, including material cost, material environmental impacts, durability, soiling resistance, and potential glare and negative impacts on pedestrian eyesight.[30]

Codes, Standards, and Voluntary Programs that Promote Cool Exterior Walls

Due to the ability of cool exterior walls to reduce building energy use and mitigate the UHI effect, several model codes and standards include provisions for their application. These include ASHRAE Standard 90.1,[31] the International Green Construction Code (IgCC),[32] which is based on ASHRAE 189.1,[33] and ANSI/RESNET/ICC Standard 301.[34] Although the prescriptive requirements for exterior wall SR and TE in ASHRAE 90.1-2022 only pertain to Climate Zone 0, which does not apply to any parts of the United States or Canada, the standard offers a small compliance credit in Climate Zones 1 and above for newly constructed buildings that use exterior wall materials with a measured SR greater than 0.25 (the wall surface must be modeled using a baseline SR of 0.25 and baseline TE of 0.90).

In addition to these model codes and standards, two U.S. states also promote the use of cool exterior walls. Hawaii's statewide building code offers a compliance credit for the installation of highly reflective exterior wall material on residential and commercial buildings.[35] The *California Green Building Standards Code* (also known as CALGreen) is a reach code that can be adopted by any California municipality, and it includes SR prescriptions for exterior walls.[36] Other jurisdictions outside of California can choose to adopt the reflective exterior wall provisions in the IgCC (2018 edition or newer) or the National Green Building Standard (ICC 700-2020).[37]

Voluntary green building programs are a third mechanism that promotes the use of cool exterior walls. For example, in April 2021, the U.S. Green Building Council (USGBC) launched a pilot credit in the LEED Rating System for Heat Island Mitigation with Cool Walls. LEED projects can earn the credit by surfacing at least 60% of the building's gross exterior wall area with a material that has an initial (i.e., unweathered) SR of at least 0.60 and initial TE of at least 0.75.[38] Additional information about codes, standards, and programs that contain provisions for cool exterior walls is available at coolroofs.org/resources/codes-programs-standards-2.

The current regulatory landscape for cool exterior walls has several limitations that are important to note. First, the codes, standards, and programs discussed above have voluntary compliance only. There are also uncertainties about how prescriptive or mandatory requirements for the use of highly reflective materials might be enforced if there is no mechanism in place, such as a building permitting process, to ensure that highly reflective materials are used when a building's exterior walls are repainted or replaced. Lastly, some existing code provisions use an incompatible metric that makes it virtually impossible to comply. As discussed in a previous section, SRI is a calculated metric that is only applicable to roofs; however, it is also included in some code provisions for exterior walls. To address this issue, several codes have been revised to include SR and TE instead of SRI. There are opportunities for improvement regarding existing and new building code requirements.

Cool Coatings in Sustainability Efforts and Marketing

In warm, sunny climates such as California, Florida, and Arizona, painting contractors, architects, specifiers, and designers may have heard of the concept of cool roofs due to state and local cool roof policies. In other parts of the country, such as northern climates that are experiencing more frequent and intense heat waves, the concept of reflective building materials may be novel. In both cases, practitioners, municipalities, and home and building owners may be unfamiliar with the concept of cool exterior walls, but are interested in practical and lower cost solutions to keep buildings and communities cooler. Paint producers and suppliers are in a unique position to educate their customers, whether professionals or individual consumers, on the benefits of cool coatings.

In recent years, sustainability efforts in the coatings industry have grown from a regulation-driven focus on minimizing volatile organic compounds to a more holistic focus on areas such as life cycle sustainability; use of renewable materials; reduced carbon footprint and more efficient operations; and human health and safety. Market drivers for sustainable products have also shifted from solely regulatory requirements to voluntary green building programs, societal demand, and even resource scarcity. As paint producers continue to promote their corporate and product sustainability, they are also relying more on independent, third-party verifications to back up their claims.[39] Promoting the radiative properties of light-colored or specially formulated exterior coatings, especially if third-party data are available, is a marketing strategy for paint companies to consider in customer-focused sustainability-centered communications.

Conclusion

The architectural coating industry is at the forefront of the growing cool exterior wall movement, both through the enhancement of customer education about the benefits of inherently cool colors or through offerings of specially formulated reflective products. Solar reflective coatings offer a promising solution to reduce solar heat gain in buildings, which can improve occupants' health and comfort in hot weather, reduce air-conditioning needs and associated energy costs, and help mitigate the adverse effects of UHIs and climate change. Resources exist for coating manufacturers to obtain credible third-party verification to support marketing and education around cool coatings and to help end users comply with codes, standards, and programs that promote their use. ❊

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